Earthquake resistant design of structures

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EARTHQUAKE RESISTANT CONSTRUCTION

BY

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INTRODUCTION

WHAT IS EARTHQUAKE ?

- Earthquake is a natural phenomenon occurring with all uncertainties
- During the earthquake, ground motions occur in a random fashion, both horizontally and vertically, in all directions radiating from epicenter
- These cause structures to vibrate and induce inertia forces on them

PRINCIPLE OF EARTHQUAKE-RESISTANT DESIGN

- The building shall withstand with almost no damage to moderate earthquake which have probability of occurring several times during life of a building.
- The building shall not collapse or harm human lives during severe earthquake motions, which have a probability of occurring less than once during the life of the building.

RULES FOR BUILDING DESIGN

- The configuration of the building (Plan and elevation) should be as simple as possible.
- The formation should generally be based on hard and uniform ground.
- The members resisting horizontal forces should be arranged so that torsional deformation is not produced.
- The structure of the building should be dynamically simple and definite.
- The frame of the building structure should have adequate ductility in addition to required strength.

CLASSIFICATION OF EARTHQUAKE

- ***Slight:*** Magnitude up to 4.9 on the Richter Scale
- ***Moderate:*** Magnitude 5.0 to 6.9
- ***Great:*** Magnitude 7.0 to 7.9
- ***Very Great:*** Magnitude 8.0 and above

SEISMIC DESIGN PHILOSOPHY FOR BUILDINGS

- Severity of ground shaking at a given location during an earthquake can be minor, moderate and strong
- Relatively speaking, minor shaking occurs frequently, moderate shaking occurs occasionally and strong shaking rarely
- As we know that the life of the building itself may be only 50 or 100 years, a conflict arises: whether to design the building to be “earthquake proof” where in there is no damage during the strong but rare earthquake shaking or should we do away with the design to building ‘
- the former approach is too expensive and the second approach can lead to a major disaster
- Hence, the design philosophy should lie somewhere in between these two extremes.

SEISMIC RISK TO BUILDING IN INDIA

The construction may generally be classified into two types:

- Non-Engineered Construction: Ex un reinforced brick masonry, stone masonry
- Semi -Engineered Construction: Ex Reinforced brick masonry
- Engineered Construction: Ex Reinforced Concrete framed structures or steel structures.

- Non-Engineered buildings are those which are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design.

- Such buildings involve field stone, fired brick, concrete blocks, adobe or rammed earth, a combination of wood with these traditional locally available materials in their construction

- the design frequently adopted in a non-engineered manner is , without taking into consideration the stability of the system under horizontal seismic forces.

- Masonry buildings of all types, except those constructed with earthquake resisting elements, are at the greatest risk of heavy damage in seismic zoneIII and of destruction to collapse in zones IV and V.

CLASSIFICATION OF SEISMIC ZONES IN INDIA

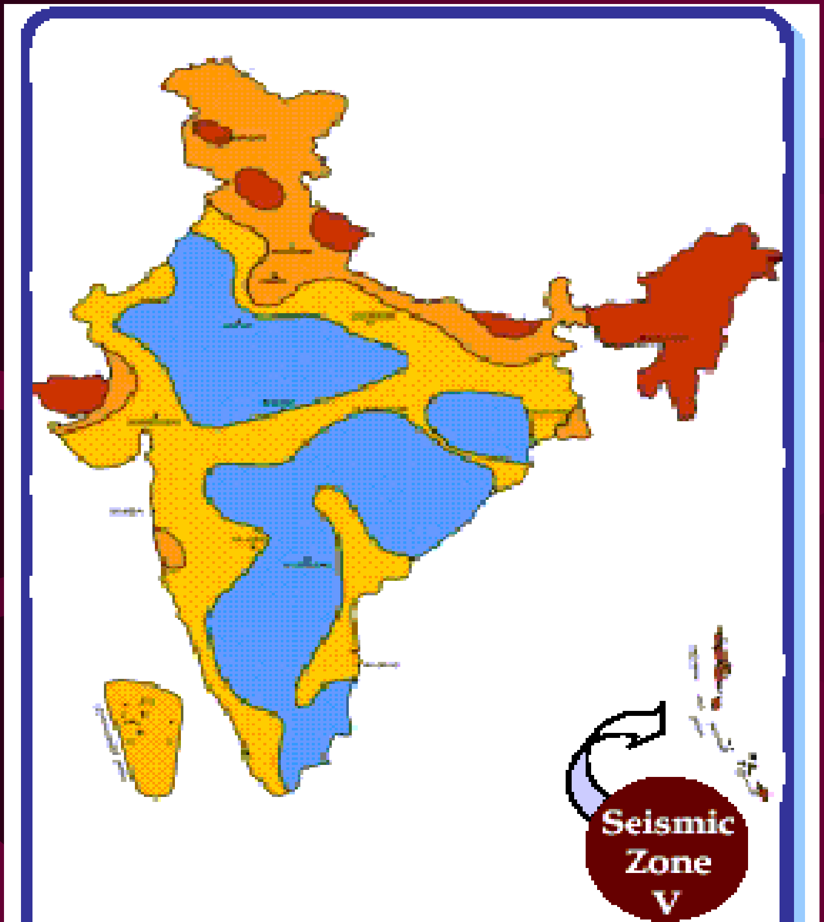
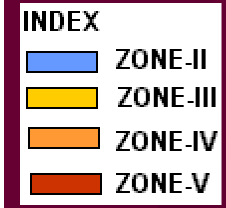


Figure 1: Seismic Zone Map of India showing *four seismic zones - over 60% of India's land under seismic zones III, IV and V.*



INDIAN SEISMIC CODES

- IS 1893-2002, Indian Standard Criteria for Earthquake Resistant Design of Structures (5th Revision)
- IS 4326-1993, Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings (2nd Revision)
- IS 13827-1993, Indian Standard Guidelines for Improving Earthquake Resistance of Low Strength Masonry Buildings
- IS 13920-1993, Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces
- IS 13935-1993, Indian Standard Guidelines for Repair and Seismic Strengthening of Buildings

SEISMIC EFFECTS ON STRUCTURES

✓ INERTIA FORCES IN STRUCTURES

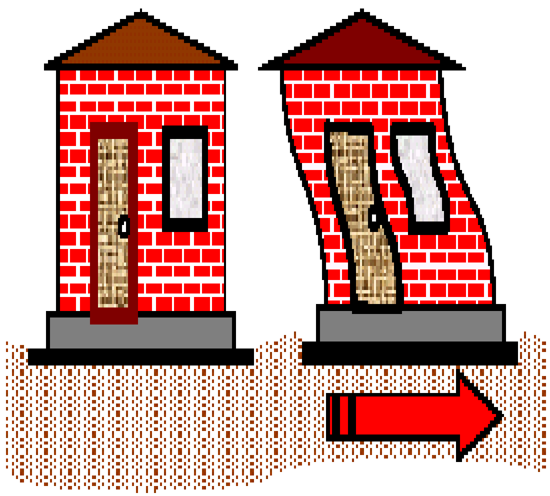


Figure 1: Effect of Inertia in a building when shaken at its base

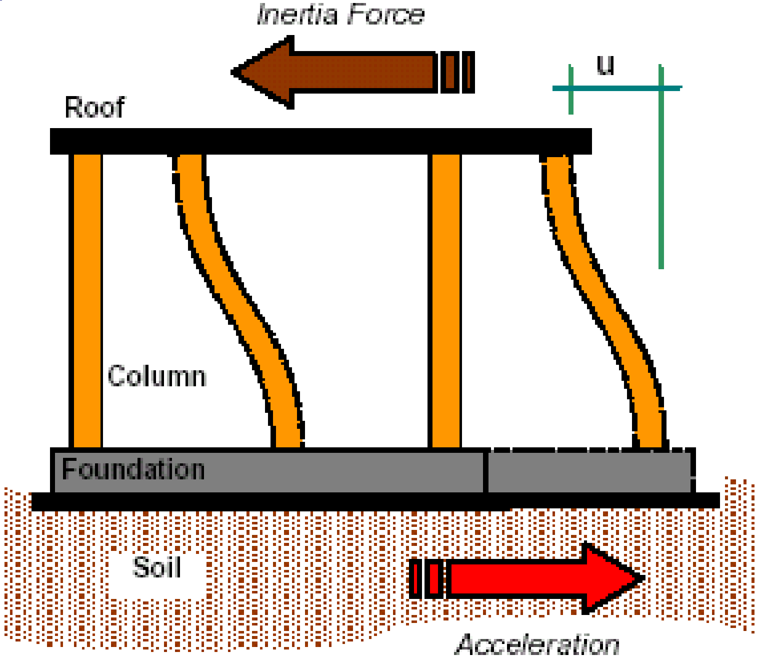


Figure 2: Inertia force and relative motion within a building

✓ HORIZONTAL AND VERTICAL SHAKING

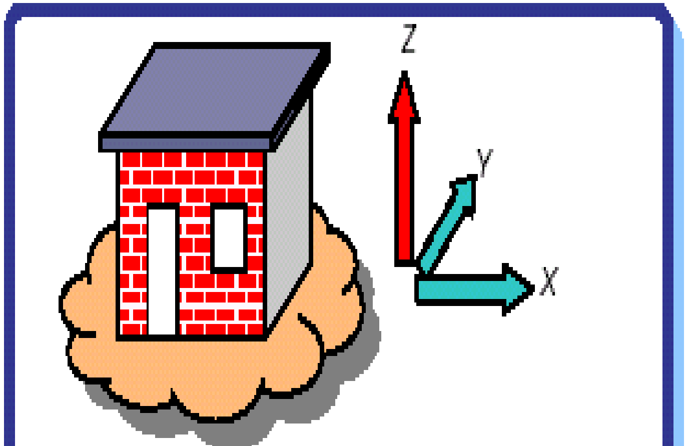


Figure 3: Principal directions of a building

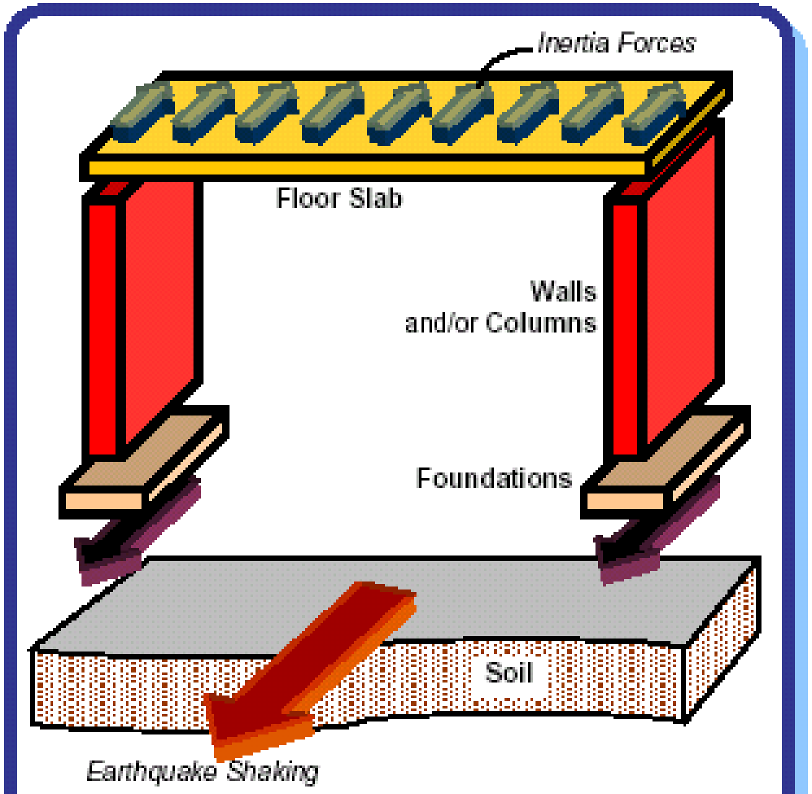


Figure 4: Flow of seismic inertia forces through all structural components.

CAUSES OF EARTHQUAKE DAMAGE

- Heavy dead weight and very stiff buildings, attracting large seismic inertia forces.
- Very low tensile and shear strength, particularly with poor mortars.
- Brittle behavior in tension as well as compression.
- Weak connection between wall and wall & roof and wall.
- Stress concentration at corners of doors and windows.
- Overall un symmetry in plan and elevation of the building
- Un symmetry due to imbalance in the sizes and positions of openings in the wall.
- Defects in construction, such as use of sub standard materials, unfilled joints between bricks.

BEHAVIOUR OF BRICK MASONRY WALL

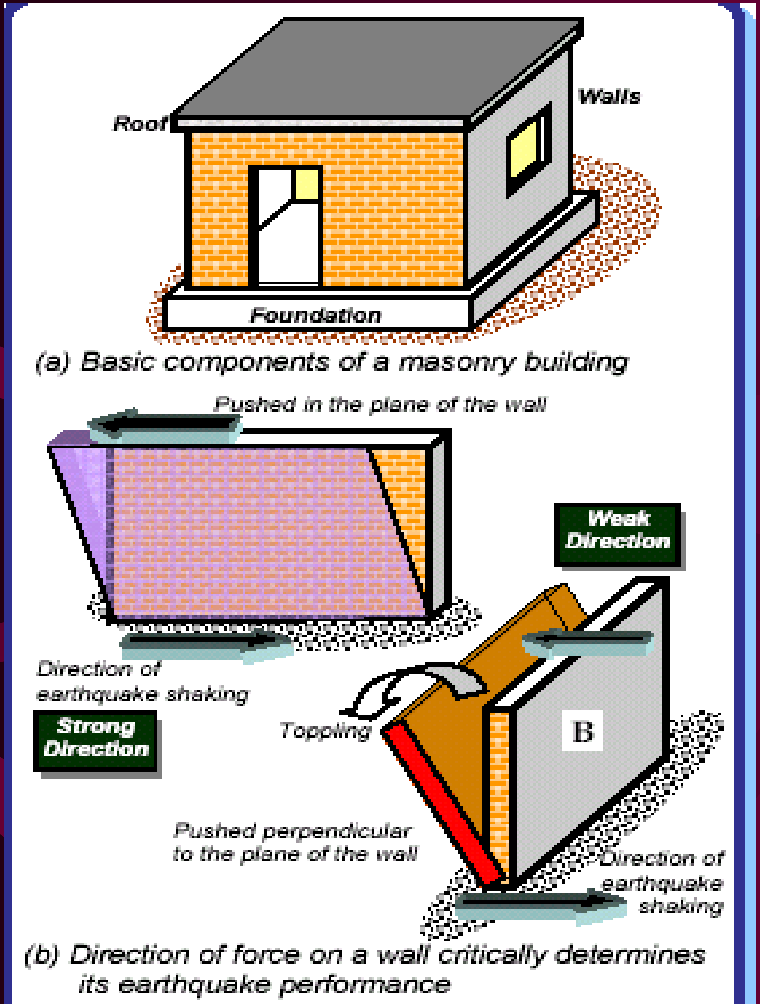
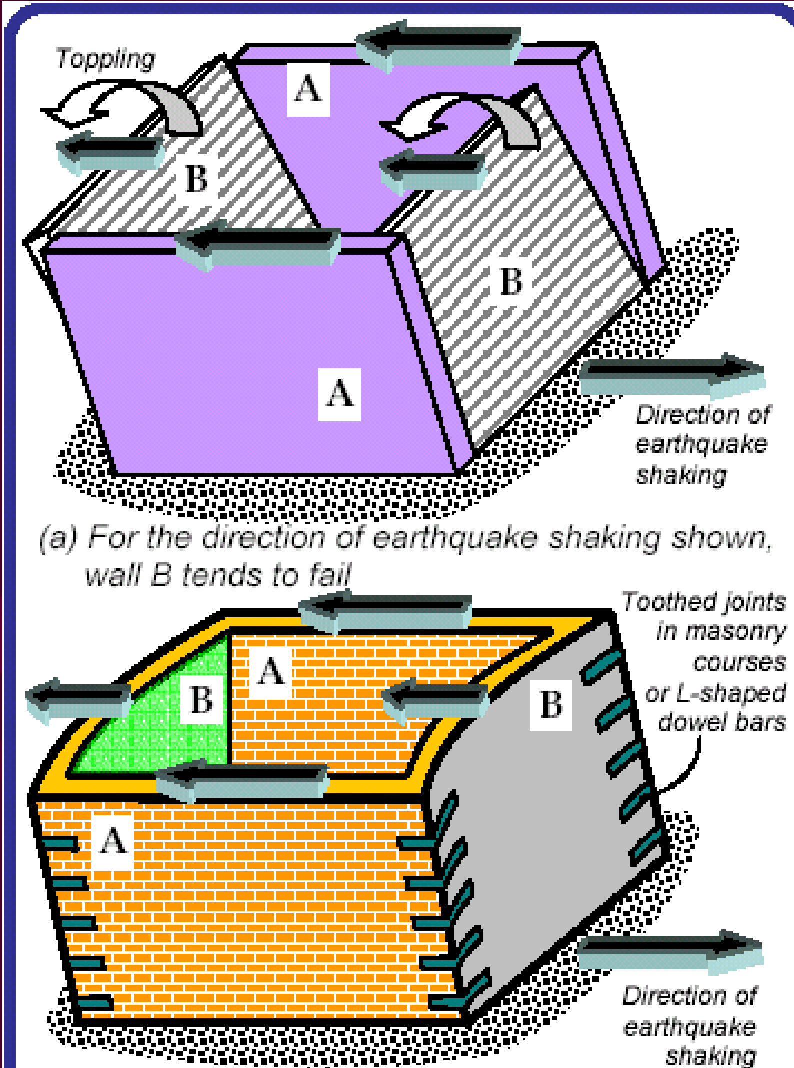


Figure 1: Basic components of a masonry building – *walls are sensitive to direction of earthquake forces.*

- Ground vibrations during earthquakes causes inertia forces to travel through the roof and walls to the foundation.
- The main emphasis is on ensuring that these forces reach the ground without causing major damage or collapse.
- Of the three components of a masonry buildings, walls are most vulnerable to damage caused by horizontal forces due to earthquake.



(b) Wall B properly connected to Wall A (Note: roof is not shown): Walls A (loaded in strong direction) support Walls B (loaded in weak direction)

Figure 2: Advantage sharing between walls – *only possible if walls are well connected.*

IMPROVING BEHAVIOUR OF MASONRY WALL

Box action: A number of construction aspects are required to ensure box action

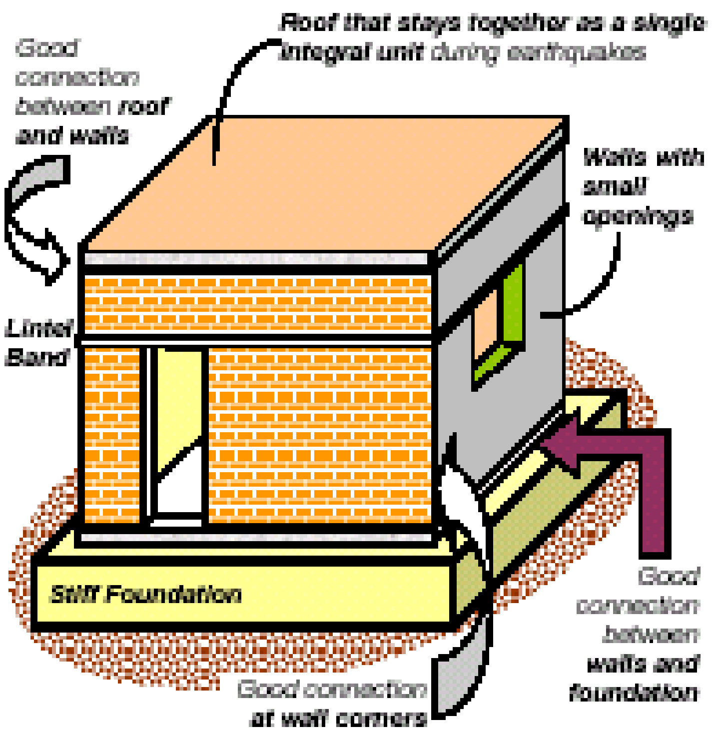


Figure 1: Essential requirements to ensure *box action* in a masonry building.

- Ensuring good interlocking of the masonry courses at the junction.
- Employing horizontal bands at various levels, particularly at the lintel level

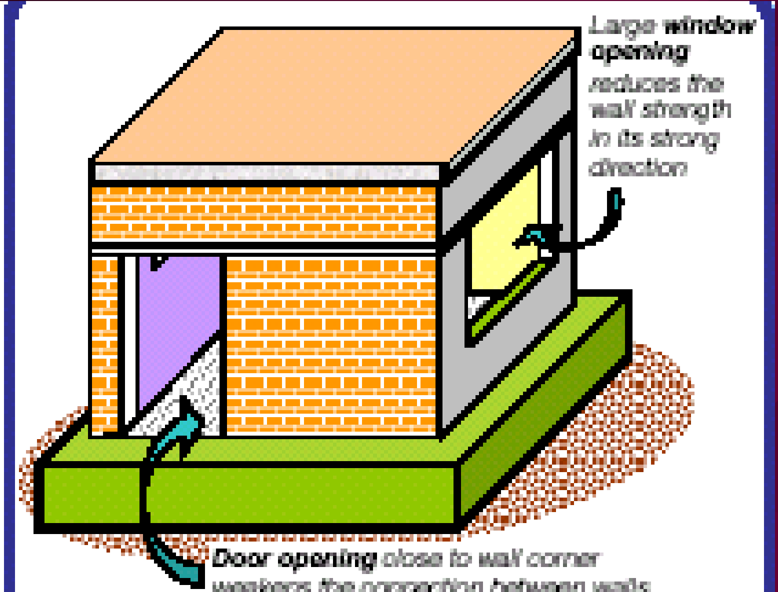


Figure 3: Openings weaken walls in a masonry building –a single closed horizontal band must be provided above all of them.

- The size of the doors and window opening need to be kept small.
- The smaller the opening, larger is the resistance offered by the wall.

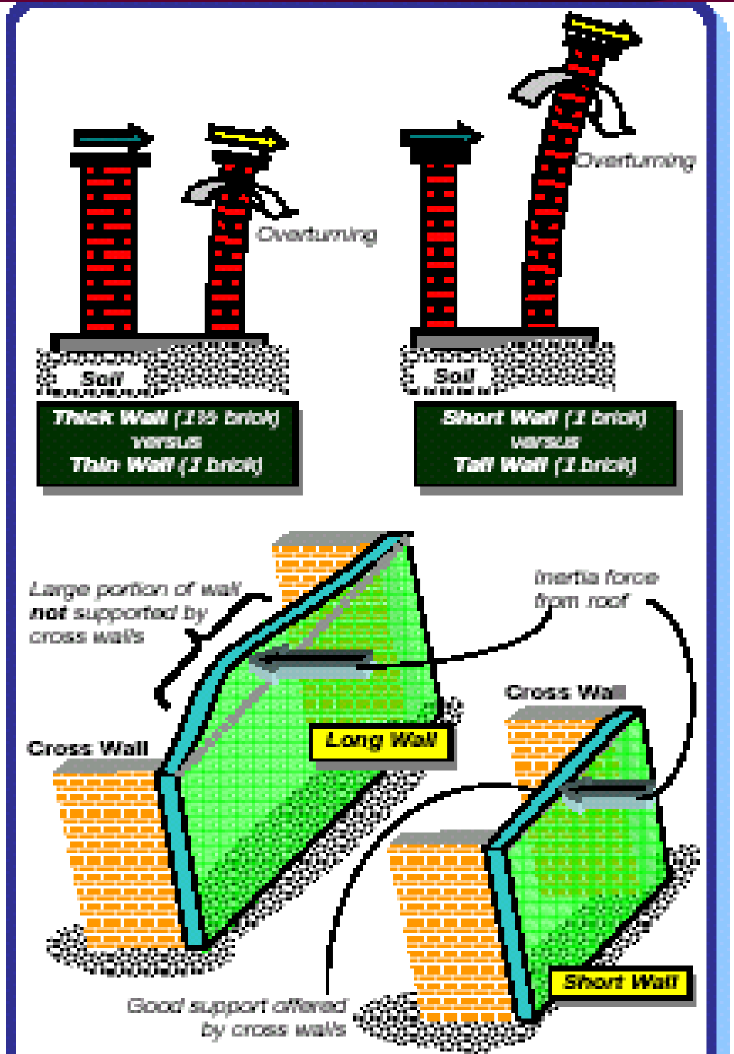


Figure 3: Slender walls are vulnerable – *height and length to be kept within limits. Note: In this figure, the effect of roof on walls is not shown.*

- The tendency of wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height-to-thickness ratios

- The length of the wall should be limited to 6m or else cross walls should be provided

IMPORTANCE OF REINFORCEMENTS IN MASONRY BUILDING

- The walls, if constructed with plain masonry would be incapable of resisting the magnitude of horizontal shear and bending forces imposed on them during earthquakes.
- For this reason, in the modern reinforced masonry systems, reinforcing steel is incorporated to resist the shear and tensile stresses, so developed.
- When these walls are subjected to lateral forces acting on them, they behave as flexural members spanning vertically between floors and horizontally between pilasters/ lateral walls.
- Therefore reinforcement in both vertical and horizontal directions is required to be provided to develop resistance against torsion.

ROLE OF HORIZONTAL BANDS

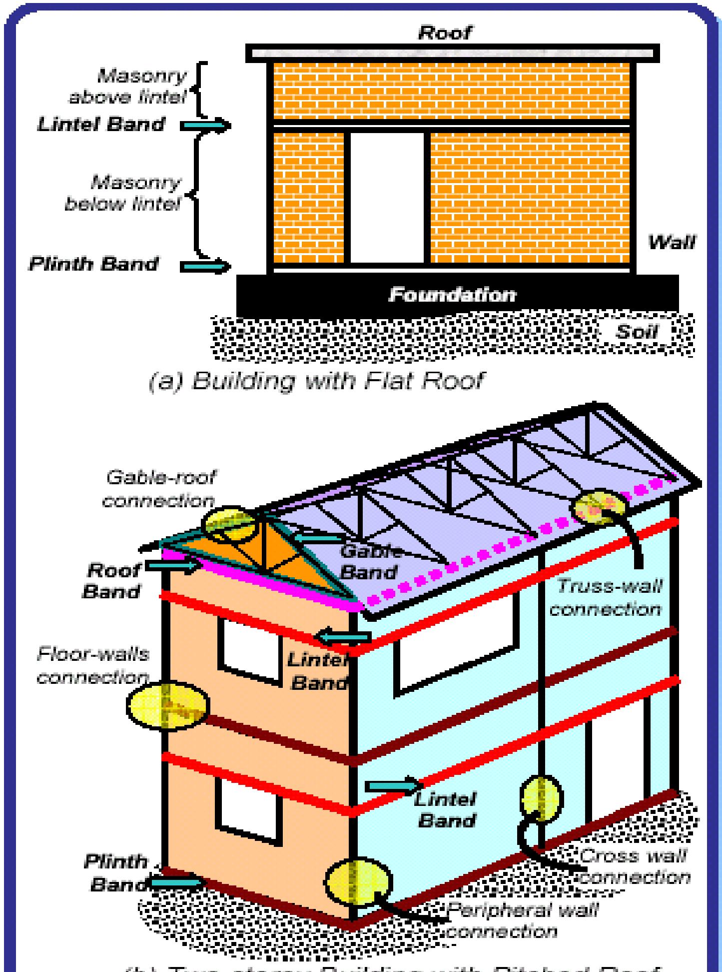


Figure 1: Horizontal Bands in masonry building – *Improve earthquake-resistance.*

- Plinth band: This should be provided in those cases where the soil is soft or uneven in their properties, as it usually happens in hilly areas. This band is not too critical.
- Lintel band: This is the most important band and covers all door and window lintel.
- Roof band: In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required because the roof slab itself plays the role of a band. However, in buildings with flat timber or CGI sheet roof, a roof band needs to be provided. In buildings with pitched or sloped roof, the roof band is very important.
- Gable band: It is employed only in buildings with pitched or sloped roofs

(a) Building with no horizontal lintel band: collapse of roof and walls

(b) A building with horizontal lintel band in Killari village: no damage

Figure 2: The 1993 Latur Earthquake (Central India) - one masonry house in Killari village had horizontal lintel band and sustained the shaking without damage.

LINTEL BANDS

- ✓ Lintel bands ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction
- ✓ This band also reduces the unsupported height of the walls and there by improves their stability in the weak direction

DESIGN OF LINTEL BANDS

bars is necessary.

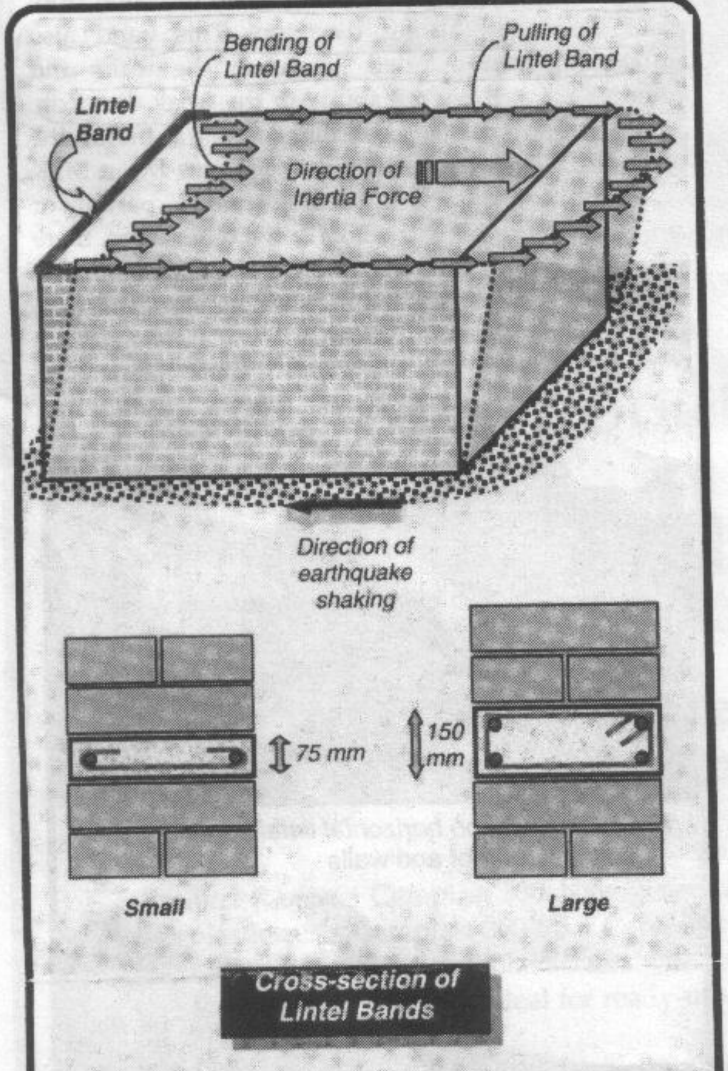


Figure 3: Bending and pulling in lintel bands – *Bands must be capable of resisting these.*

IS SPECIFICATION FOR LINTEL BANDS

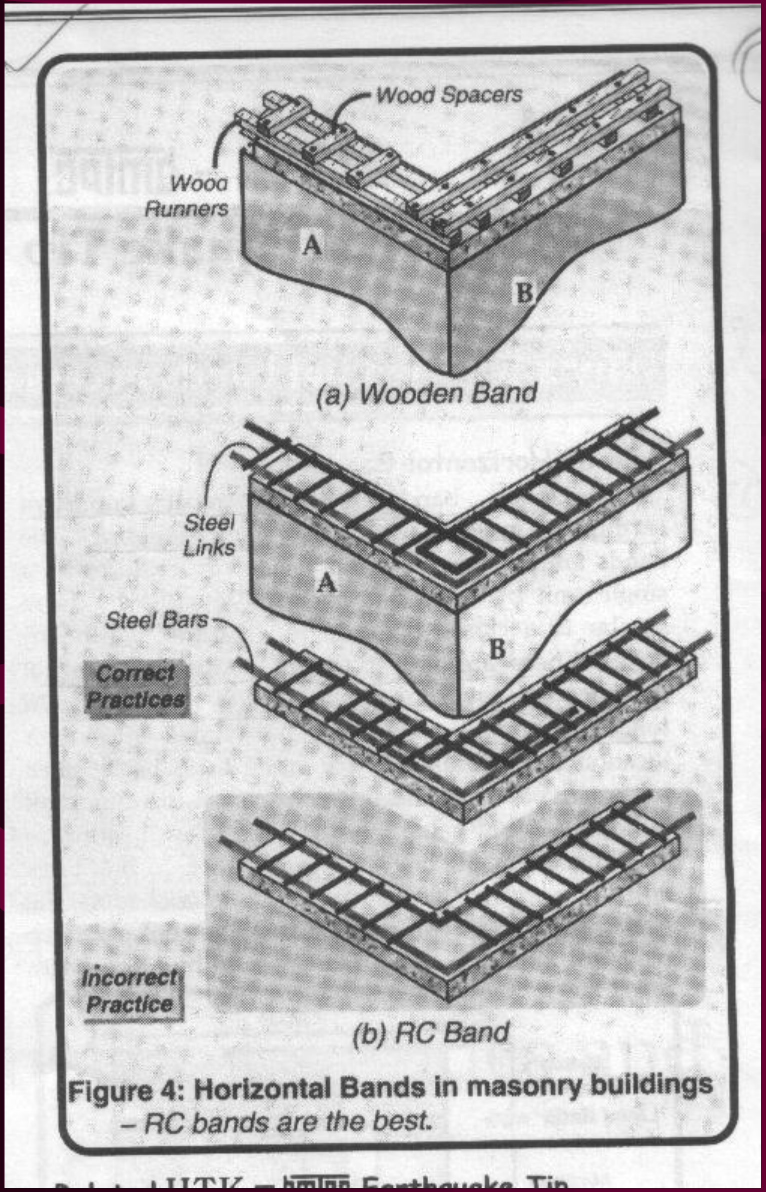


Figure 4: Horizontal Bands in masonry buildings – RC bands are the best.

- The Indian Standards IS:4326-1993 and IS:13828-1993 provide sizes and details of the bands.
- When wooden bands are used, the cross-section of runners is to be at least 75mmx38mm and the spacers at least 50mmx30mm.
- When RC bands are used the minimum thickness is 75mm, and at least two bars of 8mm diameter are required, tied across with steel links of at least 6mm diameter at a spacing of 150mm centers.

ROLE OF VERTICAL REINFORCEMENTS IN WALLS

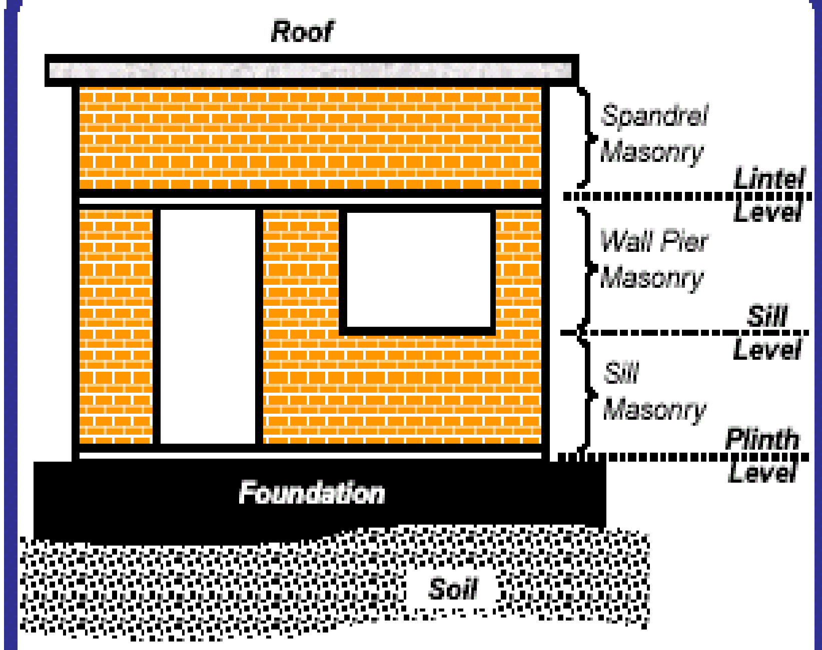


Figure 1: Sub-units in masonry building – *walls behave as discrete units during earthquakes.*

- Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls
- During earthquake shaking, the masonry walls get grouped into 3 sub-units, namely Spandrel masonry, Wall Pier masonry and Sill masonry

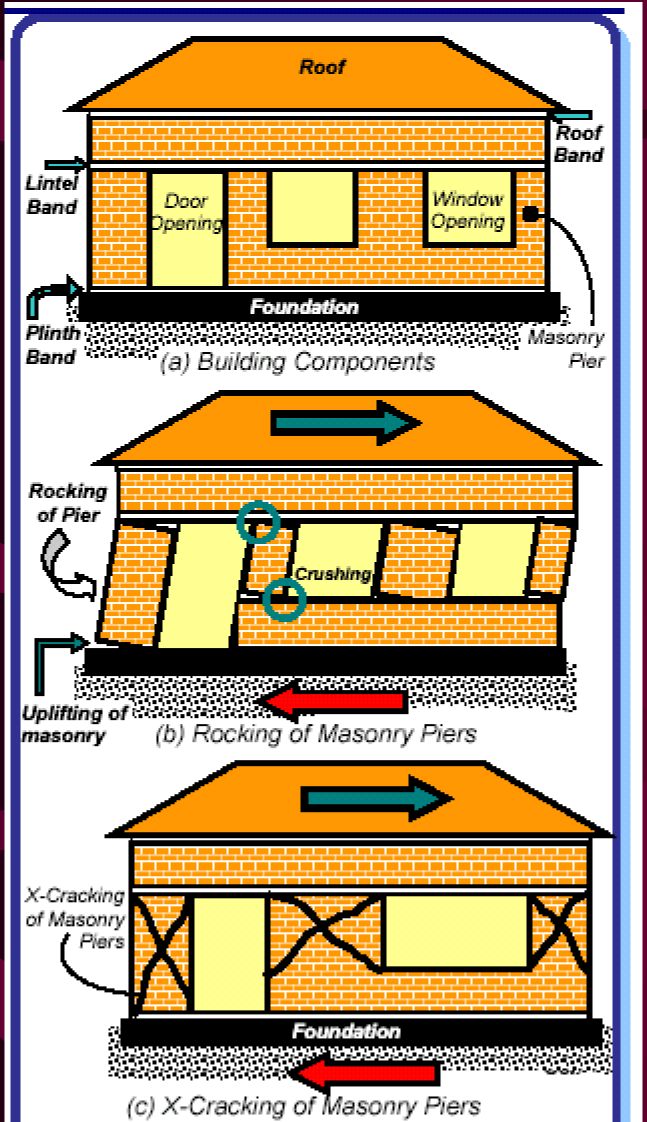


Figure 2: Earthquake response of a hipped roof masonry building – *no vertical reinforcement is provided in walls.*

- When the ground shakes, the inertia force causes the small-sized masonry wall piers to disconnect from the masonry above and below.
- These masonry sub-units rock back and forth, developing contact only at the opposite diagonals The rocking of a masonry pier can crush the masonry the corners.
- Rocking is possible when masonry piers are slender, and when weight of the structure above is small.
- Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking this is the most common failure type in masonry buildings.

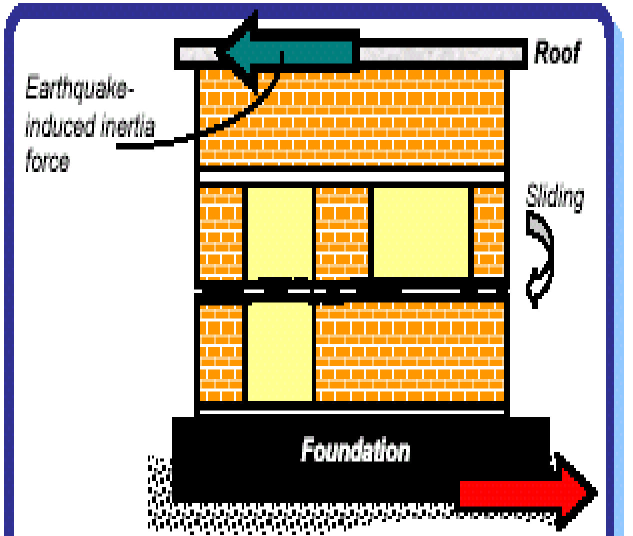
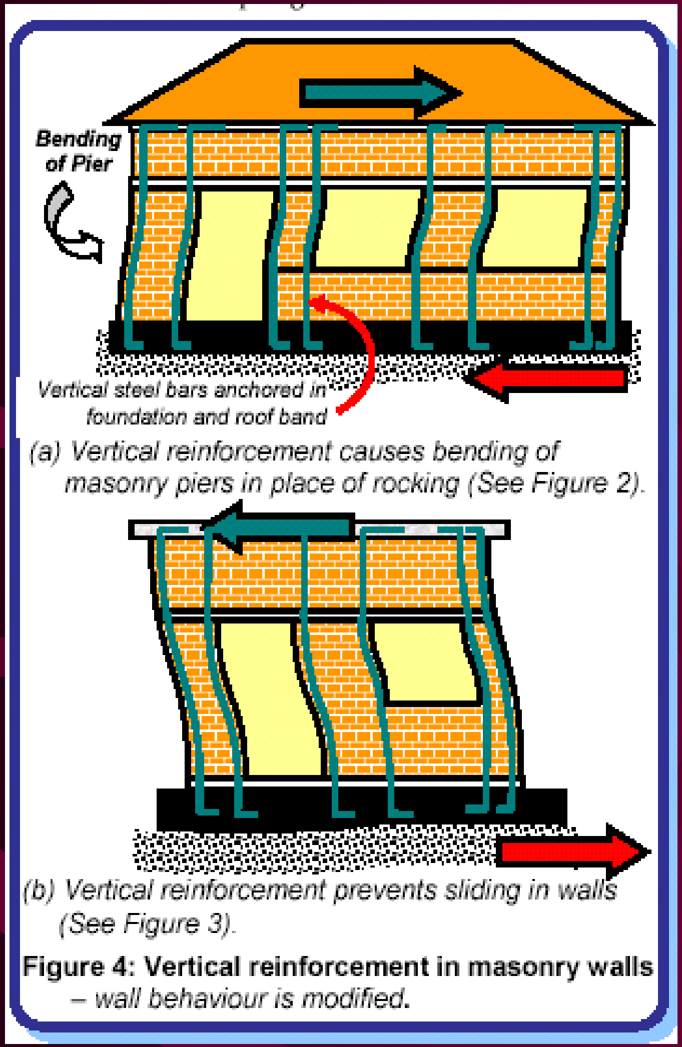


Figure 3: Horizontal sliding at sill level in a masonry building – *no vertical reinforcement.*

- During strong earthquake shaking, the building may slide just under the roof, below the lintel band or at the sill level.
- Sometimes, the building may also slide at the plinth level.

HOW VERTICAL REINFORCEMENT HELPS?



- Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top forces the slender masonry piers to undergo bending instead of rocking.
- In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking.
- Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension.
- Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.

PROTECTION OF OPENINGS IN WALL

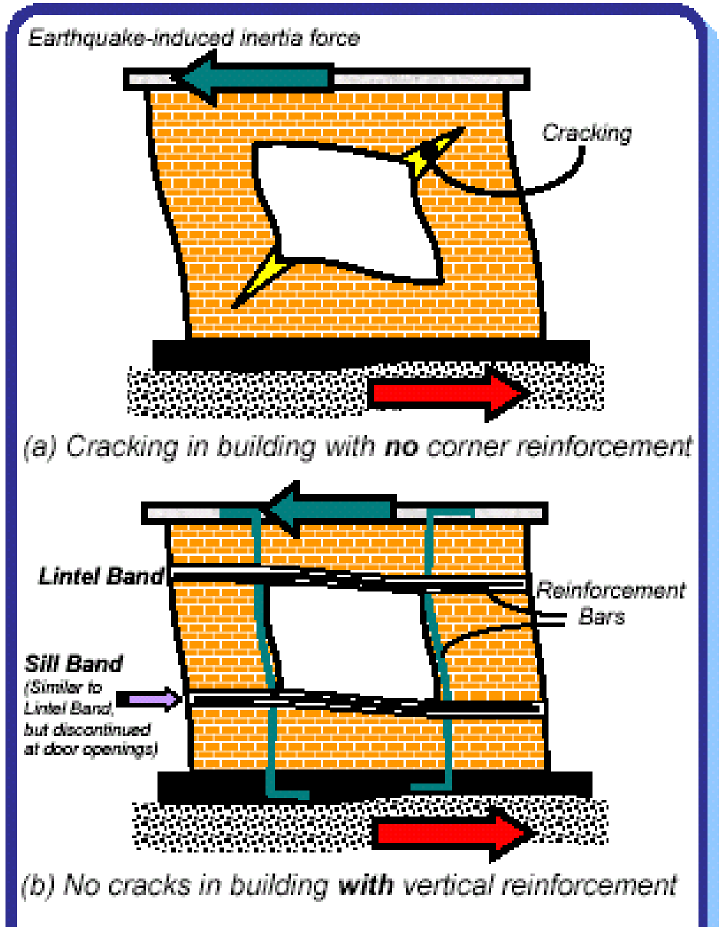


Figure 5: Cracks at corners of openings in a masonry building – *reinforcement around them helps.*

- The most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window opening.
- When a wall with an opening deforms distorts and becomes more like a rhombus.
- Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners
- Thus, lintel and sill bands above and below openings and vertical edges, provide protection against this type of damage

STRUCTURAL DESIGN

- The structure should be ductile, like the use of steel in concrete buildings. For these ductile materials to have an effect, they should be placed where they undergo tension and thus are able to yield.
- Apart from ductility, deformability of structures is also essential. Deformability of structures is also essential. Deformability refers to the ability of a structure to dispel or deform to a significant degree without collapsing. For this to happen, the structure should be well- proportioned, regular and tied together in such a way that there are no area of excessive stress concentration and forces can be transmitted from one section to another despite large deformations. For this to happen, components must be linked to resisting elements
- Damageability is another aspect to be taken into consideration. This means the ability of a structure to withstand substantial damage without collapsing. To achieve this objective “minimum area which shall be damaged in case a member of the structure is collapsed” is to be kept in view while planning. Columns shall be stronger than beams for that purpose and it is known as **strong column and weak beam concept**

TIPS FOR EARTHQUAKE-RESISTANT DESIGN

- The building plan should be in a regular shape such as square or rectangular.
- No wall in a room should exceed 6.0m in length. Use pilasters or cross walls for longer walls. In hilly terrain, it should not exceed 3.5m in length.
- The height of each storey should be kept below 3.2m.
- Don't use bricks of crushing strength less than 35kg/cm^2 for single storeyed building and of 50kg/cm^2 for 2-3 storeyed building. Only solid and sound bricks/ concrete blocks should be used
- Provide a R.C.C band of 4" thickness throughout the run along wall at lintel level passing over doors and windows.
- The thickness of load bearing wall should be at least 200mm
- The clear width between a door and nearest window should not be less than 600mm.
- Location of a door or window from edge of a wall shall be 600mm minimum.

CONCLUSIONS

- Earthquake resistant construction is important in earthquake prone area
- The building can resist earthquake forces with almost no damage
- The building shall not collapse or harm human lives during severe earthquake motions.
- However these structures will be uneconomical.

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THANK YOU